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Control Equipment for the Study of the Relation of Environment to Disease

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Control Equipment for the Study of the Relation of Environment to Disease

GEORGE L. PELTIER AND R. W. GOSS[1]
DEPARTMENT OF PLANT PATHOLOGY

INTRODUCTION

The investigation of certain plant disease problems in Nebraska has necessitated the study of the relation of various environmental factors to these diseases. The control of these environmental factors in the greenhouse studies has been obtained by the use of previously described apparatus or their modification and adaptation, along with new methods which have been devised to meet the needs of these investigations. In view of the widespread interest in the subject of environmental control for experimental studies, it was deemed advisable to present briefly the methods now in use in this department in the hope that the information may be of assistance to workers in other institutions.

The authors were exceptionally fortunate in having had an opportunity, before coming to Nebraska, of using the apparatus and methods employed for such studies in other institutions; one of the authors having been familiar with the methods used by Dr. James Johnson and Dr. L. R. Jones and his staff at the University of Wisconsin in controlling soil temperatures and the other with the methods used by Dr. C. F. Hottes at the University of Illinois in the control of air temperatures and other factors. The apparatus and methods described in this paper are largely a combination and adaptation of the above methods, with the exception of the control of low temperatures.

The chief aim of the authors in their investigations has been the study of certain disease phenomena rather than the invention of apparatus. It has therefore been considered essential that the apparatus in use be as simple as possible so that the entire time of the investigators would not be taken up in controlling the apparatus. In addition it has been advisable to construct all equipment as cheaply as possible. For these reasons it has sometimes been necessary to sacrifice ex-

[1]The authors have shared equally in the development of the equipment described in this paper.

treme accuracy of control for simplicity and low cost. The authors believe that the control of temperatures within a range of 1° to 2° C. is all that is essential in most greenhouse experiments; if more accurate control is necessary, more expensive equipment is essential and more time must be spent in its regulation. The equipment described in this paper has been used for several years and has been found to be accurate enough for the problems under investigation. It can be operated for the most part by a trained greenhouse man, thus relieving the investigator for other necessary work.

GREENHOUSE CONTROLS

For all experimental studies requiring considerable space and where great accuracy of temperature control was not essential, the usual steam heated greenhouses have been used. By the use of Johnson Service Co. thermostatic steam controls and careful ventilation, the temperature of each greenhouse can usually be kept within a range from 2° to 3° C. In this way, a series of greenhouses at different temperatures ranging from 15° up to any desired higher temperature can be obtained from October 1 to May 1 in this climate.

Apparatus for the more accurate control of soil and air temperatures as described in the following pages can also be placed in any of the greenhouses having a temperature slightly below that desired in the control apparatus.

Low temperature greenhouse.—In order to accurately control temperatures below 20° C. during most of the year, it has been found necessary to use artificial refrigeration. The principle employed was that of cooling a large room by refrigeration to a temperature below that required, and to install electrically heated and controlled soil and air temperature cases and incubation chambers for the desired temperatures in this room. For this purpose a portion of a greenhouse was walled off into a room 8 feet wide by 25 feet long. A double glass wall and roof having 2 inches dead air space were installed on all exposed sides of this room. The usual side wall ventilation was allowed to remain for supplementary refrigeration from outside during cold weather (figure 2).

A 1½ ton automatically controlled indirect ammonia refrigeration system was installed in the head house, as shown in Figure 1.

The system comprises a motor driven ammonia compressor (figure 1, 1 and 2), ammonia cooling coils immersed in a brine tank (figure 1, 9), a motor driven centrifugal pump (figure 1, 14) for circulating the brine thru coils in the greenhouse,

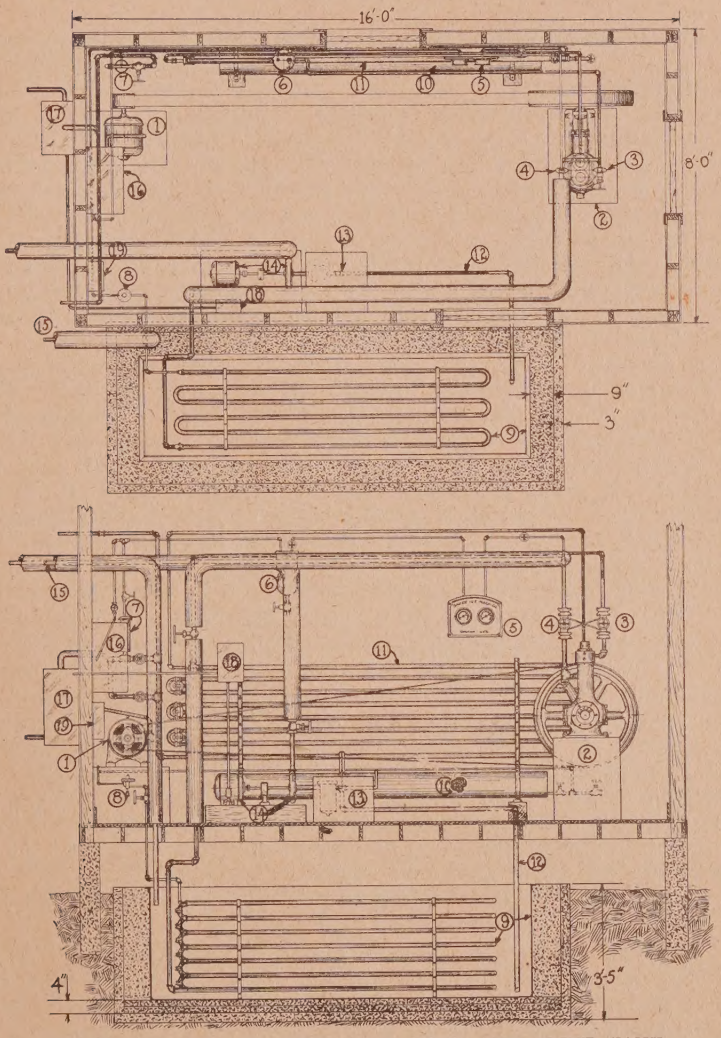


FIG. 1.—DETAILS OF COMPRESSOR ROOM AND BRINE TANK.

1. Motor. 2. Two-cylinder Baker compressor. 3. Main discharge valve. 4. Main suction valve. 5. Gauge board. 6. Oil trap. 7. Automatic water valve. 8. Automatic ammonia expansion valve. 9. Steel brine tank and brine tank coils. 10. Liquid receiver. 11. Condenser. 12. Brine discharge line. 13. Thermostatic temperature regulator for brine. 14. Brine pump and motor. 15. Brine return line. 16. Automatic controller for starting and stopping motor. 17. Main switch. 18. Brine pump motor switch. 19. Switch for fan in low temperature room.

and various automatic control devices. The electric controller (figure 1, 16), for automatically starting and stopping the compressor motor, is put into operation by closing the line switch. This controller is equipped with a low voltage and overload release. An electric thermostat (figure 1, 13) is immersed in the brine line between the tank and the brine pump, and is connected to the electric controller so that the ammonia compressor is started and stopped to maintain the brine within a 5 degree centigrade range of the temperature for which it is set. An automatic valve (figure 1, 7) is installed to control the flow of water thru the ammonia condenser, according to the pressure of the ammonia therein. As the pressure of the ammonia rises, the valve opens wider. As the pressure drops the valve closes, so that when the compressor is shut down the flow of water is cut off entirely. The pressure of the ammonia in the condenser also actuates the electric controller (figure 1, 16) in order to shut down the compressor should the pressure rise too high, due, say, to failure of cooling water. An automatic expansion valve (figure 1, 8) is installed to control the flow of liquid ammonia from the receiver (figure 1, 10) to the cooling coils in the brine tanks (figure 1, 9). This expansion valve is operated according to the pressure of the ammonia in the cooling coils.

The steel brine tank, 10 x 2½ x 3 feet, is set in a concrete pit and well insulated with granulated cork as shown in Figure 1, 9. This tank contains 375 feet of low pressure ammonia coils surrounded by the calcium chloride brine. The brine is pumped thru about 750 feet of coils placed in a well insulated bunker about 20 feet long adjoining the low temperature room in the greenhouse. These coils are arranged in a staggered manner (figure 2, 9), so that by means of valves the brine can be circulated in every alternate coil. During a period of low outside temperatures, only one set of coils is turned on. It is only during warm days and bright sunshine that both sets of coils are used. A large steel pan placed under the coils catches the drip from the coils, which is drained off.

Figure 2 shows the detail plans of construction and installation of the equipment in the low temperature greenhouse. One end of the bunker opening directly into the low temperature room is 3½ feet wide and extends the full height of the bunker. At the other end is a vertical shaft with a horizontal opening of about 12 square feet at a height of 6 feet from the floor. About half way down this shaft and situated directly in front of the coils is a 24-inch fan which circulates the warm air from the top of the greenhouse over the coils in the bunker

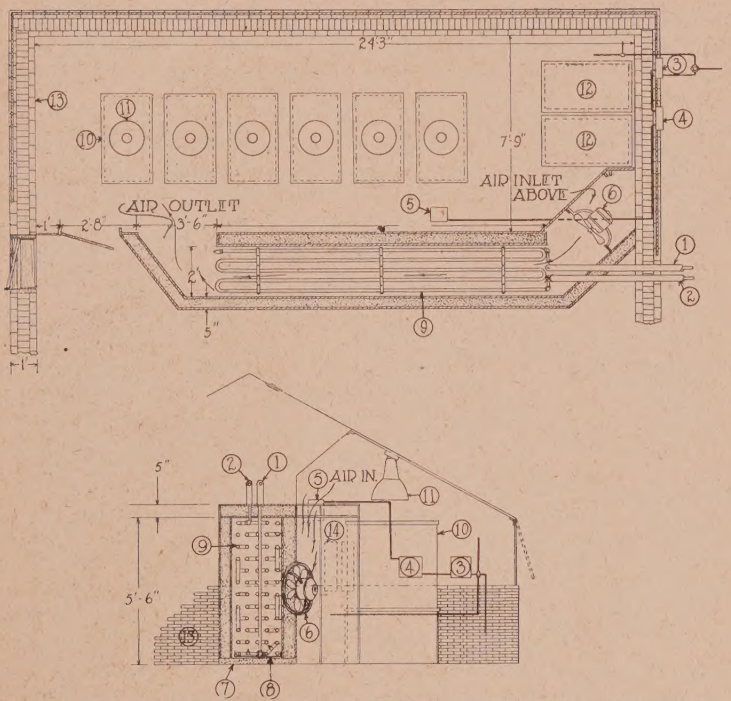


FIG. 2.—DETAIL PLANS FOR LOW TEMPERATURE ROOM IN GREENHOUSE

1. Cold brine intake. 2. Warm brine return. 3. To switch in compressor room. 4. Magnetic switch control of thermostat. 5. Electric thermostat. 6. I. G. L. self cooled 24″ fan. 7. Well insulated bunker. 8. Drip pan. 9. Brine coils. 10. Temperature cases. 11. Bowl reflectors and electric lights. 12. Incubation chambers. 13. Brick wall of greenhouse. 14. Door into fan chamber.

and discharges the air at the opposite end of the bunker into the low temperature room. By measurements with an anemometer it has been found that about 2,000 cu. ft. of air per minute is circulated over the brine coils. The fan is controlled by an electric thermostat placed in the center of the room about 5 feet high. This control works on a range of 2° to 3° C.

By means of this equipment it has been found possible to maintain temperatures below 5 ° C. from October 1 to May 1. The chief difficulty encountered in controlling low temperatures has been the effect of bright sunlight on the glass roof rather than the effect of high outside temperatures. The effect of sunlight makes it very difficult to maintain a constant

temperature altho it is possible to maintain a temperature as low as 2° to 5° (plate 1, C.) by the additional use of removable cheesecloth shades on the roof during certain periods of the day.

The authors have found it desirable to conduct practically all their experiments within the electrically heated and controlled temperature cases installed in this room (plate 1, A). Thus it is possible to allow the temperature of the room to drop as low as it will during the night so that a considerable rise in the temperature during the day will not bring the maximum temperature above 5 ° C., which was the lowest temperature maintained in the temperature cases. During cold weather the greenhouse ventilator can be opened and the brine pump shut off; in this way a very low temperature is obtained in the greenhouse (plate 1, B) and the temperature of the brine tank is lowered to about -25° thus establishing a reserve of refrigeration capable of preventing any great rise in temperature during the day even with intense sunlight.

The above apparatus differs from other possible types of refrigeration, chiefly in two ways. First in the type of refrigeration, *i. e.*, indirect ammonia system rather than the direct ammonia, the carbon dioxide, or the sulphur dioxide systems. Second, in the refrigeration of a large room and the use of electrically heated and controlled temperature cases placed in it, instead of the direct refrigeration of the individual temperature cases in which the plants are to be grown. These methods have been used because it is considerably easier to accurately control electric heating units than it is to control refrigeration. In this method, it is also possible to allow the temperature of the room to drop as far as possible during the night, thus allowing for considerable increase during the day when the refrigerating plant is under its peak load. The chief advantages of the type of refrigeration machine used lie in its compactness and low cost as compared with the carbon or sulphur dioxide types of refrigeration. Indirect refrigeration by brine circulation was used because direct ammonia expansion was not considered practical owing to difficulty in control, lack of reserve refrigeration, and danger of ammonia leaks. If a larger greenhouse than that here employed is to be used, a larger refrigerating machine should be installed, as the present machine has to work at its maximum capacity during most of the time. This complete equipment has been found reasonably low in cost of installation and operation, and efficient in control.

CONTROL OF SOIL FACTORS

Soil moisture.—In conducting experiments involving the control of the soil moisture content, the authors have not considered it practical to attempt to maintain a constant soil moisture content by the use of atmometers or by other methods often employed. Inasmuch as there is not any great effect on disease phenomena in most instances with a very slight change in the soil moisture content, extreme accuracy of control was sacrificed for increased population which is not usually possible with the more accurate methods.

Two types of containers have been used. In experiments in which the plants are to be grown in soil temperature tanks or soil and air temperature cases as described in the following pages, a galvanized iron container, made to fit the temperature apparatus, is used, as shown in Figure 3. These containers hold 10 to 12 kilos of soil. In experiments conducted in the open greenhouse, 3-gallon earthenware crocks are employed holding about 12 kilos of soil.

Enough soil is prepared in the fall to complete one season's experiments. The soil-moisture equivalent is determined from composite samples and at the start of each experiment the soil moisture content (dry weight) is determined. All soil moisture contents are based on the moisture equivalent, as this standard has been found much more reliable in the accurate duplication of experiments than the old method of determining the moisture holding capacity.

The surface of the soil is usually covered with about 1 kilo of coarse gravel or sand to decrease evaporation and prevent fluctuating temperatures of the surface soil. Various other materials have been tried but have been found to be more expensive and less satisfactory. Water is added partly on the surface and also by the use of a reservoir consisting of a small inverted clay pot filled with gravel, placed several inches deep, which is fitted with a glass tube extending several inches above the surface of the soil. By these methods the soil moisture has been found to be very well distributed thruout the container.

The amount of water to be added is determined by frequent weighings. The plants are watered frequently enough so that usually not more than 100 to 150 c. c. of water is required. Thus the departure from the desired soil moisture content is not greater than 1 per cent dry weight.

This method has been found very practical and its use has yielded considerable information regarding disease phenomena.

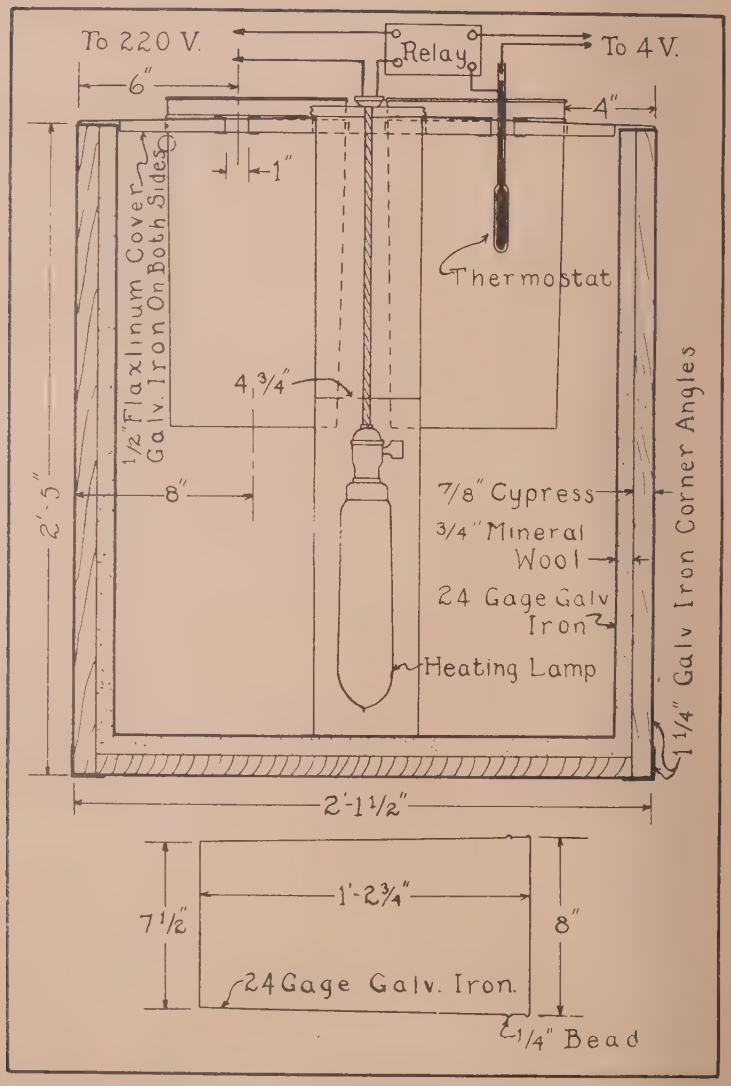


FIG. 3.—Section of soil temperature tank showing construction and arrangement of apparatus.

Soil temperature.—The control of soil temperatures has been obtained by the use of the "Wisconsin soil temperature tanks." Slight modifications in these "tanks" have been made to meet the local needs but the principle employed is essentially the same. In these "tanks," which are in reality well insulated water baths, the plants are grown in the containers previously described, which are immersed in the water to a level with the surface of the soil. The standard "tank" employed in our experiments is shown in detail in figure 3. The water is heated by a 250 or 500 watt electric heating bulb or other heating appliances. These heating units are controlled by a mercury thermostat, which is immersed in the water. A small amount of glycerine is placed on top of the mercury in the capillary tube to prevent oxidation and decrease capillarity. This thermostat is connected with the heating units thru a 50 ohm pony relay, with the points reversed, which is controlled by a storage battery. This entire apparatus is cheap and efficient and is accurate within a range of 1 ° C. on either side of the desired point. If greater accuracy is required, other types of water thermostats can be used, usually at a greatly increased cost.

These tanks can be used in one greenhouse when the same air temperature is desired; or they can be moved to different greenhouses, thus obtaining a combination of different soil and air temperatures.

CONTROL OF ATMOSPHERIC FACTORS

Air temperature.— For the control of air temperature, glass cases which fit on the soil temperature tanks were built. The frame was constructed of clear well-seasoned white pine. Doors almost the full width and height of the case were placed at both ends allowing easy access to the interior. A dead air space of 1½ inches was obtained by the use of double glass walls. A thick layer of felt was nailed to the bottom frame of the case (figure 4).

The heating elements were made as follows: Twenty feet of chromel wire (No. 24) was wound on a narrow strip of transit and fastened to a large piece of the same material. One heater was placed on each side of the case and they were connected in series. A small pilot light was connected in parallel with the heaters. A Johnson Service Co. electric thermostat was connected in parallel with the heaters and suspended in the center of the case. The thermostat works thru a 50 ohm pony relay with the points reversed, which was connected to a storage battery. The pony relays and storage

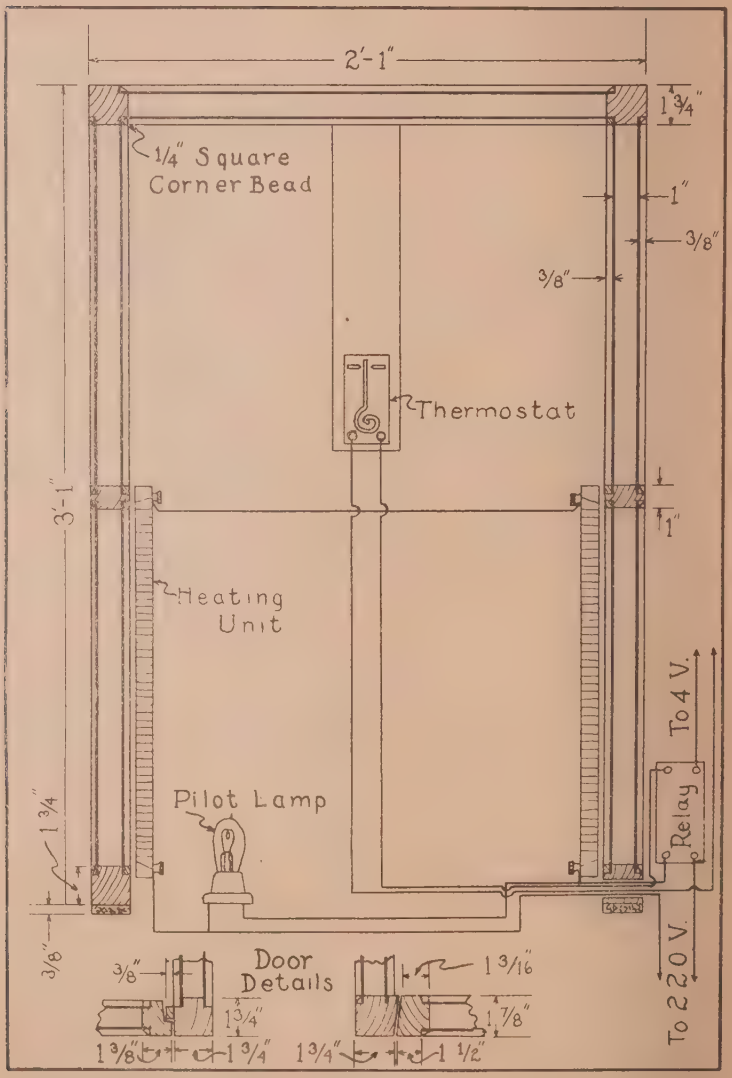


FIG. 4.—Section of air temperature case showing construction and arrangement of apparatus.

battery are not as satisfactory as the Johnson Service Co. special relays which are connected directly to the main line; the latter, however, are more expensive.

This equipment has given very satisfactory results. Like the soil temperature tanks the air temperature cases are standard and can be moved from one greenhouse to another.

Light.— During the season of the year that the control equipment is in operation in the greenhouse, the sunlight both as regards the duration and intensity is the most variable factor. In order to supplement sunlight during cloudy days or to increase the duration of light, artificial light was used.

Large bowl reflectors (17 in. diameter) together with 1000 watt nitrogen filled lamps (Mazda C) were placed at a height of 2 feet above the temperature cases. As installed these lights produced approximately 450 foot-candles inside the cases.

On several of the cases a set of curtains were arranged so that artificial light could be used entirely. On the whole, however, these lights are used at the present time to supplement sunlight in order to bring about a more normal growth of the plants.

In one greenhouse there has been installed a set of 10 reflectors and lights arranged 2 feet apart and about 3 feet from the greenhouse bench. Here again they have been employed for the most part to supplement sunlight.

Along one side of a greenhouse a series of compartments equipped with electric lights have been constructed for a study of the relation of light to disease. The compartments are built on a false bottom 8 inches from the floor. The individual compartments made of beaver board are 36 x 42 inches, the front of each compartment extending to the greenhouse roof, 84 inches from the floor; and the rear walls and partitions, which are 55 inches high, extend to the eaves of the greenhouse. This allows for the circulation of air between the compartments above the partitions. The front of each compartment is fitted with a heavy curtain running in grooves. The curtains and walls were painted with several coats of white enamel, while the roof and the glass sides of the greenhouse were painted to cut off the light from the outside.

A series of bowl reflectors of various sizes with lamps of different candle power were installed in the center of each compartment. They were so hung that the lower edge of the reflectors was 3 inches below the top of the partitions. At the present time lamps of 50, 100, 200, 300, 500, 750, and 1000 watts are being used.

With the false bottom and the open space at the top together with a system of electric fans, enough circulation of air is obtained in each compartment to take care of the heat produced by the lamps so that the temperature variation is not over 2° to 3° C.

COMBINATION OF SOIL AND AIR FACTORS

The air temperature cases and the soil temperature tanks previously described can be combined in order to control various combinations of air and soil temperatures. When different soil and air temperatures are desired with the same set of plants, the air temperature cases are placed directly over the soil temperature tanks and they are each controlled in the same way as when used individually (plate 2). When the same soil and air temperature is desired, the cases and tanks are again combined. The water is drained from the tanks, the cover is removed, and the cans are placed on a stand at the same level as before. The heaters are removed from the sides of the air temperature cases and placed at the bottom of the tank, and the thermostat is lowered to a point just above the containers.

With the electric light equipment previously described, the same or different amounts of light can be used for the various cases. The same or different soil moistures can be maintained in the various cases or in the different cans in the same cases. By the use of humidostats the same or different relative humidities could be maintained in the various cases. Thus all combinations of temperatures, light, and moisture may be obtained as desired with this equipment.

INCUBATION CHAMBERS

For plants.— In studying the relation of environment to disease it is important to determine the temperatures suitable for initial infection and the period of incubation with plants of various ages, but especially with seedlings. To accomplish this, incubation chambers in which a saturated atmosphere can be maintained and in which the temperature can be held constant are necessary. The incubation chambers used were soil temperature tanks with the lid and containers removed. A stand made of laths placed one-half inch apart was placed in the tank and the water surface kept one-fourth to one-half inch below it. By means of the automatic equipment described for the control of soil temperatures the water can be kept at the temperature desired. Over the top of the tank was placed

a glass sash, and a layer of felt was used to make a close union with the tank. Owing to the large volume of water present, these modified tanks serve most admirably for incubation chambers for seedling plants. A large population at a uniform temperature can be obtained and a heavy film of water is produced on the plants.

When temperatures below 20° C. are desired, these chambers are placed in the low temperature room.

For cultures.— It is often necessary that the growth-temperature relations of the causal organism be determined as one phase of the study of the relation of environment to diseases. For this purpose a series of incubators with a range of temperatures from near 0° to 35° C. is necessary. In obtaining a series of low temperature incubators for cultural work the same principle as that described in the low temperature greenhouse was employed.

Accordingly 4 two-door iceboxes (14x22x36 inches, inside measurements) were obtained, the ice compartment dismantled and two extra shelves put in each box so that the working capacity of the boxes was doubled. These boxes were equipped with heaters made as follows: Twenty feet of chromel wire (No. 24) was wound on each of two strips of transit connected in series and fastened to the underside of a large (12x19 inches) transit plate having a row of holes in the center the length of the plate. The whole was then set up from the floor of the boxes (2½ inches) by means of porcelain insulators.

A Chicago Surgical and Electric Co. thermostat was connected up in parallel with the heaters. The thermostats were fastened in the center of the back wall of the boxes. Pilot lights were inserted in the line between the heaters and thermostat (plate 3).

The incubators were installed in a cold storage room which was maintained at a temperature of about 4° C. The thermostats in the incubators were so set that temperatures of 5°, 10°, 15° and 20° were maintained in their respective incubators. These incubators hold as constant a temperature as that obtained with the same type of thermostats in the laboratory and have been found very satisfactory. For temperatures above 20 °, ordinary bacteriological incubators with the same type of thermostat are used in the laboratory.

The equipment herein described has been satisfactorily employed in the study of various plant disease problems, and its application to specific studies has already been published in the following articles:

Peltier G. L.

A Study of the Environmental Conditions Influencing the Development of Stem Rust in the Absence of an Alternate Host.

I. The Viability of the Urediniospores of *Puccinia graminis tritici* Form III. Neb. Agr. Sta. Res. Bul. 22, pp. 1-15, 3 figs., September, 1922.

II. Infection Studies with *Puccinia graminis tritici* Form III and Form IX. Neb. Agr. Sta. Res. Bul. 25, pp. 1-52, 12 pls. December, 1923.

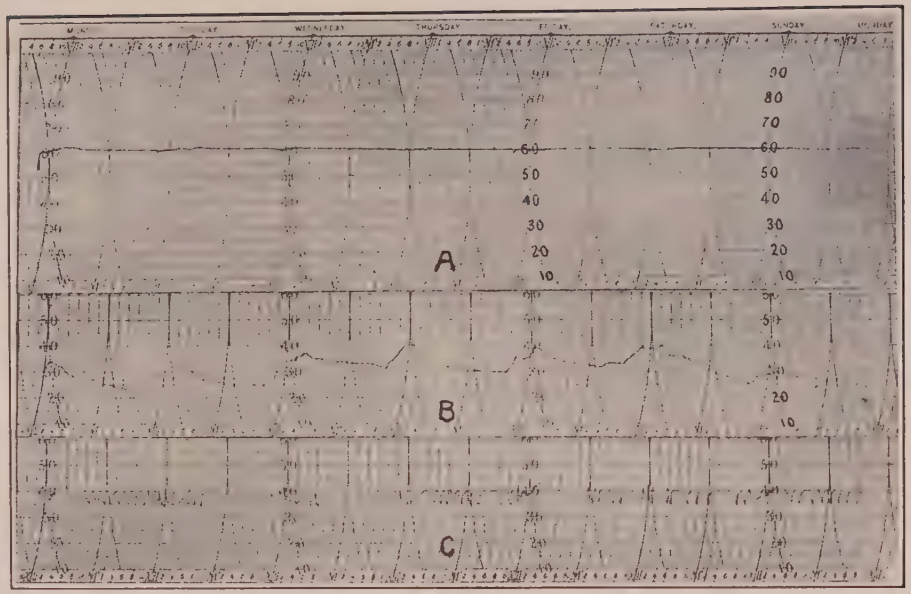
Goss, R. W.

Relation of Environment and other Factors to Potato Wilt Caused by *Fusarium oxysporum*. Neb. Agr. Exp. Sta. Res. Bul. 23, pp. 1-84, 3 figs., March 1923.

Effect of Environment on Potato Degeneration Diseases. Neb. Agr. Exp. Sta. Res. Bul. 26, pp. 1-40, 3 figs., March 1924.

Potato Wilt and Stem-end Rot Caused by *Fusarium eumartii*. Neb. Agr. Sta. Res. Bul. 27 (in press).

(Edition 5723-3M)



TYPICAL TEMPERATURE CHARTS

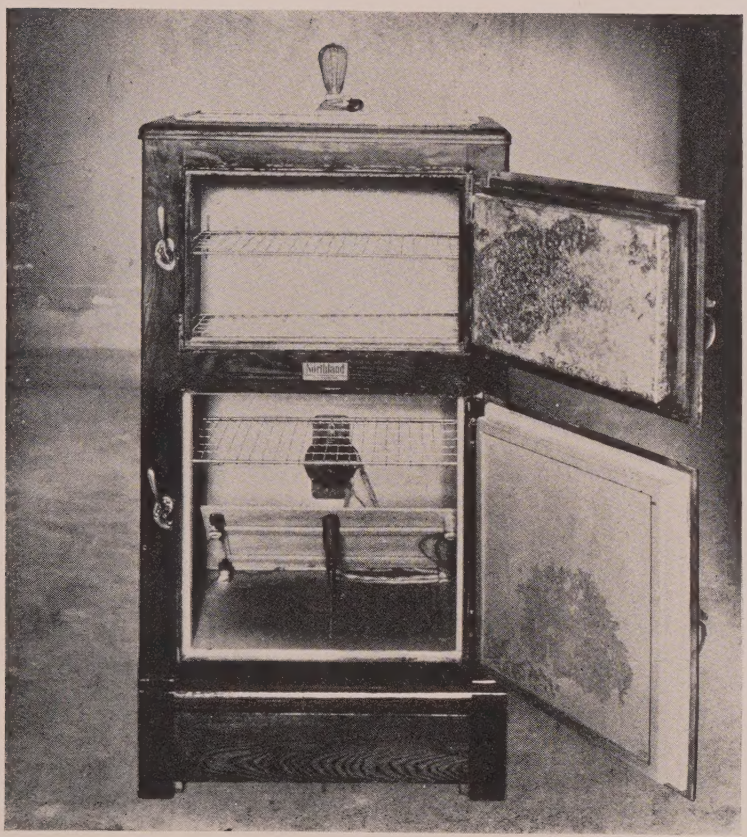
A. Of temperature case in low temperature room (same control can be obtained with either automatic or hand regulation as shown below).

B. Of low temperature room in greenhouse using hand regulation and ventilation when outside temperature is 0° C. or below.

C. Of low temperature room in greenhouse with thermostatic control of fan, (thermograph placed on top of cases at point where highest temperatures of the room are recorded).

PLATE 1

Equipment for the control of different soil and air temperatures.



Interior of incubator showing arrangement of control apparatus. (Heating units raised to show construction.)

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